variation, but in general it was estimated at 10 to 12 meters. Bow No. 2 was only one-half to two-thirds as wide and bow No. 3 only about one-third as wide as No. 1. The secondary bow, No. 4, had about the same width as No. 1.

In bow No. 1 the beams of sunlight entered the droplets of water directly and underwent reflection and refraction as in the regular rainbow, but the manner in which bows No. 2 and No. 3 were produced is not so clear. A difference in the size of the drops affects the angular distance of the bow, but it scarcely seems credible that this factor was responsible for these supernumerary bows. It seems more probable that the beams of light which produced them, first impinged upon the surface of the lake and were then reflected into the droplets.

The horizontal rainbow which was seen on May 24, 1915, possessed some features which deserve attention. As already stated it is the only one that has been observed in any other season of the year than autumn. It was visible from 6:45 a. m. to 8:30 a. m., and consisted of a single series of spectral colors. The right segment only was noted and it was complete during a considerable portion of this time. During the remainder of the time only the bright distal portion of the segment was visible.

The bright portion at the outer extremity of the bow increased in width as the sun rose higher above the horizon. At 7:20 a. m. it did not appear to be more than 5 meters wide; at 7:45 it was at least 10 meters wide, and by 8:10 a. m. its width was estimated at 30 meters; a launch resting in the rainbow and at right angles to it served as a good unit of measurement in making the last estimate. Blue and violet constituted nearly half of the bow when it reached its maximum width.

Also as the sun rose higher, the bright portion of this horizontal rainbow approached the observer, and just before its disappearance, about 8:30 a. m., the intervening distance was only 115 meters.

In conclusion it may be said that the conditions which appear to be necessary for the production of this phenomenon on Lake Mendota are as follows: (*a*) A scum or film on the surface of the water which may consist of an oily soot or of plankton organisms, generally algæ; (*b*) a fog which deposits minute drops of water on this scum; (*c*) a perfect calm which facilitates the formation of the scum and also permits the globules of moisture to remain as individual droplets; (*d*) a bright sun.

551. [illegible]

HALOS AT FORT WORTH, TEX., AND THEIR RELATION TO THE SUBSEQUENT OCCURRENCE OF PRECIPITATION.

By HOWARD H MARTIN, Assistant Observer.

[Dated, Weather Bureau, Fort Worth, Tex., Feb. 23, 1916.]

The halos recorded in the following tables were observed at Fort Worth, Tex. (lat. 32° 43′ N.; long. 97° 15′ W.). The record of halos has constituted a portion of the daily routine of a regular Weather Bureau station, established September 1, 1898. However, early unfamiliarity with the practical methods of halo observation brought about the record of many halos prior to 1910 with insufficient details as to attending phenomena. In practically all cases the actual hour of occurrence, the duration and the angular measurements were omitted. For this reason, and that these results may be compared with those obtained at York, N. Y., only those halos noted between January 1, 1910, and December 31, 1915, are used. It is believed that since January 1, 1910, not more than 5 per cent of all solar halo phenomena have escaped record.

TABLE 1.—*The number of solar and lunar halos observed at Fort Worth, Tex., Jan. 1, 1910, to Dec. 31, 1915, inclusive.*

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1910	7	1	2	5	5	2	0	3	0	1	5	3	34
1911	4	2	5	3	4	2	2	0	0	0	3	2	27
1912	6	3	3	5	5	3	2	0	0	4	1	1	33
1913	3	2	5	1	2	2	6	1	0	5	1	1	29
1914	2	3	0	1	1	4	5	0	0	4	2	1	23
1915	2	6	2	2	1	1	0	1	2	0	2	5	24
Total	24	17	17	17	18	14	15	5	2	14	14	13	* 170
Means	4.0	3.0	3.0	3.0	3.0	2.3	2.5	0.9	0.3	2.3	2.3	2.1	28.2
Smoothed means [1]	3.3	3.2	3.0	3.0	2.8	2.5	2.0	1.2	1.0	1.7	2.2	2.5	28.2

* Of this total, two are discarded in other results because of incomplete data.

[1] E. g., January $= \frac{\text{Dec.} + 2\,\text{Jan.} + \text{Feb.}}{4}$

Table 1 includes both solar and lunar halos noted during this period, showing their relative monthly frequency without regard to the time of occurrence. It will be readily seen that this section of the country observes far fewer halos than either Blue Hill Observatory, Mass., or York, N. Y. The possible reason for this may be the fact that as Fort Worth is far south of the usual cyclone "lanes," it is favored with the cirro-stratus advance guard from only those lows of the Alberta type that recurve far enough south to affect the weather at this station at all, and from the relatively infrequent southern Pacific type, moving eastward from the arid regions.

Table 2 shows the frequency with which these halos were followed by precipitation, and the average length of time before such precipitation occurred. The results show even less uniformity, with regard to the seasonal effects than do either the York, N. Y., observations or those obtained at Blue Hill. The normal length of time elapsing before precipitation (24.1 hours) is much in excess of that at York, N. Y. (20.5 hours), and of that at Blue Hill (15.6 hours). Halos at Fort Worth are by far most frequent in January, and least frequent in September. In fact, during the entire record of 18 years, but two halos, one solar and one lunar, have been recorded in the latter month.

TABLE 2.—*Relations of occurrence of halos to the occurrence of precipitation at Fort Worth, Tex., from Jan. 1, 1910, to Dec. 31, 1915, inclusive.*

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Total number considered	23	17	17	17	18	14	15	5	2	14	13	13	168
Per cent followed by rainfall within 18 hours	17	36	28	23	28	20	23	20	50	50	22	23	26
Per cent followed by rainfall within 24 hours	22	53	33	30	40	27	30	40	50	60	36	46	36
Per cent followed by rainfall within 36 hours	39	70	44	30	61	33	30	40	50	70	66	56	48
Per cent followed by rainfall within 48 hours	55	88	50	70	72	33	48	60	50	70	66	56	59
Per cent not followed by rain in 60 hours	33	12	50	30	28	64	48	20	50	20	34	44	32
Average duration	1.8	1.7	1.8	1.9	2.0	1.9	1.8	1.7	1.8	1.8	1.9	2.0	1.8
Average hour of occurrence (first seen)	15.2	17.3	14.8	14.6	15.5	12.5	13.6	11.0	17.0	12.6	12.7	13.8	14.2
Average number of hours between halo and precipitation	25.5	23.2	22.4	28.7	22.2	25.1	26.8	31.8	27.0	17.3	21.4	17.7	24.1

The wind direction during and immediately following the observation of a halo seems to play an important part in its verification as a rain prognostic. Of the 168 halos recorded, 94 were attended or followed by easterly winds and falling pressure. Of these, 82, or 87 per cent, were followed by precipitation within 48 hours. This result is important, in view of the fact that of the total number of halos recorded, but 99, or 59 per cent, were followed by rain or snow within 48 hours.

Unusual displays, Fort Worth, Tex.—Complex halos are rare indeed. Even the 46°-halo occurs but infrequently. From the time angular measurements were first made at this station, seven 46°-halos have been recorded. On the evening of May 23, 1901, two parhelia were noted as the sun was about 10° above the western horizon. They appeared on the edge of a bank of alto-stratus clouds. Between this edge and the horizon the sky was clear, while above the clouds were so dense as to obscure all evidences of the parhelic circle [?]. The parhelia were about 23° distant from the sun.

At about 6 p. m. on July 2, 1914, a complex halo with three parhelia was observed. The two brightest parhelia were vertically above and below the sun, while the parhelion to the south or left of the sun was but little more than an irregular splotch of light. The phenomenon lasted about 45 minutes, and occurred during a general rain over western Texas; for this reason it is supposed that this station was in the outskirts of the alto-stratus cloud region. No color was observed in the phenomenon, and no rain followed at Fort Worth within several days.

Many of the 22°-halos occur with a cirro-stratus overflow which precedes the incoming high. These halos are almost invariably followed by northerly winds and rarely by precipitation. Local thunderstorms are frequently preceded by halos, usually solar and occurring during the morning hours. These halos are followed by the usual meteorological conditions preceding a thundershower. It is also observed that halos occurring with brisk south winds and falling pressure will not be followed by rain if the wind shows a tendency to increase in velocity and shift to the southwest, but that halos followed by southwest winds and rising pressure will almost invariably be followed by rain within 24 hours.

Halos are not infallible weather signs, but when properly considered in conjunction with other features they serve as a material aid to the forecaster.

55/.5?7

ORIGIN AND MAINTENANCE OF THE EARTH'S ELECTRIC CHARGE.[1]

By W. F. G. SWANN.

(Read at the special meeting on atmospheric physics of Section B, American Association for the Advancement of Science, San Francisco, Aug. 5, 1915.)

[Author's abstract.]

The paper consists of two parts. Part I is devoted to a general discussion of certain broad principles which must be considered in the formation of any theory of atmospheric-electric phenomena, and to a consideration of former theories. In Part II a new hypothesis is provisionally formulated, and its consequences are traced.

Part I commences by considering the possibility of a general circulation in the atmosphere by which the negative electricity flowing upward at one place is conducted down at some other place. It appears that such an explanation is untenable, for no regions have been discovered presenting the phenomenon of a continual return current, and apart from this fact, the existence of a circulation of the kind depicted would necessitate that the electromotive forces around closed paths, in which the flow was taking place, would have to be of the order of magnitude of 10^5 volts. *Electrostatic* forces can contribute nothing whatever to a line integral around a closed circuit. A consideration of such values of the line integral as could be obtained on the basis of the change of magnetic induction due to the earth's magnetic field through a closed circuit, or of the motion of the earth and atmosphere in the magnetic lines of force of the earth shows that, apart from the circumstance that they would be of a nature unsuitable to correspond to the facts, they would be of an order of magnitude entirely too small to play any appreciable part in the phenomena.

The various possible types of hypotheses which may be made to account for the maintenance of the earth's charge are capable of being grouped under three heads: (1) We may imagine that negative electricity is fed into the earth from the outside in some unspecified manner. In this case it will be necessary to assume that the vertical conduction current is dissipated again into space. (2) We may imagine that negative electricity is supplied continuously to the earth and positive electricity to the atmosphere at all places. (3) We may imagine that negative electricity is supplied continuously to the earth and positive electricity to the atmosphere, the supp taking place, however, over only a limited region at any one time.

Considering the hypotheses of the first type, it turns out that in view of the fact that the earth is a comparatively good conductor of electricity, the charge will distribute itself uniformly over the earth's surface. The known fact that the conductivity continually increases with altitude to a high value is all that is necessary to insure that things will arrange themselves so that the positive charge in the atmosphere is equal to the negative charge on the earth.

Considering the hypothesis of type 3, it turns out that in regions where the replenishment of charge to the earth and atmosphere is not taking place, the potential-gradient and earth-air current-density would, under ordinary conditions, quickly fall to an insignificant value. If, however, a very high value is assumed for the conductivity of the upper atmosphere, this difficulty to some extent vanishes, and the assumption of a replenishment of the charge at one place is sufficient to account for the maintenance of atmospheric-electric phenomena at all places.

A discussion of several former theories is given; among others, those of Elster and Geitel and of Ebert. In these theories a separation of positive and negative electricity takes place in such a way that negative electricity is left on the earth and positive is supplied to the atmosphere. The positive charge is carried upward by the ascending air currents, and in the steady state; the convection current so produced must be equal and opposite to the conduction current. Apart from the objections which have been raised by others against the Elster and Geitel theory, it is shown that, owing to the conductivity of the atmosphere, the rising positive electricity would become devoured, as it were, before it had reached any great altitudes, and the net result is that on such a theory the potential-gradient and earth-air current-density would be expected to diminish to practically a zero value at altitudes of the order of magnitude of 1,000 meters, which is contrary to the results of balloon experiments. The objection here cited applies to any form of theory in

[1] Reprinted from Carnegie Institution of Washington, Yearbook No. 14, for the year 1915, pp. 339-341. (Text of the paper appears in full in "Terrestrial Magnetism," September, 1915, 20:105-126.)